Guidance on
Geologic Monitoring for Vital Indicators

National Park Service
Geologic Resources Division
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Introduction

Geologic monitoring can be used to detect long term environmental change, provide insights into the ecological consequences of those changes and to help determine if the observed changes dictate a corrective action in management practices. Geologic indicators can be used to assess whether environmental change is within a normal or anticipated range of variation. Geologic indicators include measurements of change in volcano activity, earth movement, glacier advance and retreat, shoreline movement, sand dune movement or mobilization, sediment storage and loading, soil erosion, thermal feature activity and temperature change, and slope and rock stability, among others.

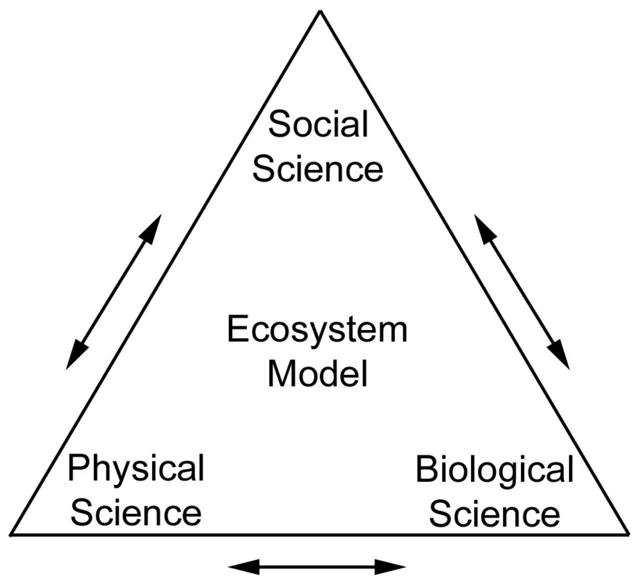
Linkage

Geologic monitoring activities can be linked to existing laws, regulations, agency strategies, and planning processes. The overarching drivers are the NPS Organic Act, the Government Performance and Results Act (GPRA), and the 1998 NPS Omnibus Act. Resource-specific geology legislation includes the Federal Cave Resources Protection Act (1988), Coastal Barrier Resource Protection Act (1982), Geothermal Steam Act (1970), and Wild and Scenic Rivers Act (1968).

In addition, park enabling legislations often address specific direction for geologic resources management. Over 160 parks have significant geologic resources and 83 parks exist because of a geologic theme. NPS Management Policies, Director's Orders and initiatives (such as the Coral Reefs Initiative) can also provide guidance for monitoring of geologic features and processes. Geologic monitoring should be addressed in a park's General Management Plan (GMP), Resource Management Plan (RMP) and possibly in the Visitor Experience and Resource Protection Plan (VERP).

Why is Monitoring of the Physical Component of the Ecosystem Important?

It is unrealistic to attempt an evaluation of ecosystem function without considering the landscape and earth systems. Biological systems depend upon and interact with abiotic components. Without water, soil, rock, and atmospheric components, we are ignoring critical parts of the ecosystem. Physical systems can be bellwethers of significant ecosystem change. Changes in physical systems can have significant impacts on human health and safety and human activities can, in turn, force changes in physical systems.



Effective resource management is based on understanding the ecosystem, not just one or several of its component parts. In developing an ecosystem study model for science-based management, it is important to consider the contributions of social, physical and biological sciences. Monitoring the physical component provides important information on the complex interactions that take place with the ecosystem.

What Physical Components of the Ecosystem Need to be Monitored?

The physical component of the ecosystem is comprised of three basic parts, geology, hydrology and meteorology. Within these disciplines, changes in the ecosystem can be observed through measurements of the magnitudes, frequencies, rates, and trends of physical processes. Measurements that are particularly useful as indicators for detecting ecosystem change include processes occurring at or near the Earth’s surface and those subject to change over periods of 100 years or less. The Commission on Geologic Science developed a list of these "geoindicators" during a three-year international project for Environmental Planning (International Union of Geological Sciences). For the purpose of evaluating NPS geologic monitoring needs within parks and networks, we have chosen to use Geoindicators as an assessment tool. On the following page is a checklist of the 27 geoindicators. The entire list is included, but the Geologic Resources Division will only be responsible for the 18 geologic indicators, shown with an asterisk.

GEOINDICATOR	Importance for this Park	Natural Influence	Human Influence	Understanding Past Environments
Alpine and polar				
*Frozen ground activity		H	M	H
*Glacier fluctuations		H	L	H
Arid and Semi-arid				
*Desert biotic crusts and pavements		H	H	M
*Dune formation and reactivation		H	H	M
*Wind erosion		H	M	M
Dust storm magnitude, duration and frequency		H	H	M
Coastal				
Coral chemistry and growth patterns		H	H	H
*Relative sea level		H	M	H
*Shoreline position		H	H	H
Groundwater-related				
Groundwater chemistry in the unsaturated zone		H	H	H
Groundwater level		M	H	L
Groundwater quality		M	H	L
*Karst activity		H	M	H
Surface water				
Lake levels and salinity		H	H	M
Surface water quality		H	H	L
*Stream channel morphology		H	H	L
Streamflow		H	H	L
*Stream sediment storage and load		H	H	M
Wetlands extent, structure, and hydrology		H	H	H
Hazards				
*Volcanic unrest		H	L	H
*Seismicity		H	M	L
*Slope failure (landslides)		H	H	M
Other (multiple environment)				
*Soil and sediment erosion		H	H	M
*Soil quality		M	H	H
*Subsurface temperature regime		H	M	H
*Sediment sequence and composition		H	H	H
*Surface displacement		H	M	M

* - Geologic indicators
H - HIGHLY influenced by, or with important utility for
M - MODERATELY influenced by, or have some utility for
L - LOW or no substantial influence on, or utility for

Use of Geoindicators as a Tool

Geoindicators have been developed as tools to assist in an integrated assessment of natural ecosystems. Working with geologic specialists, monitoring networks can use the geoindicator checklist and the 18 geologic monitoring parameters (see appendices) to ensure adequate planning for the monitoring of geoindicators. Preliminary assessment of which geoindicators to include as vital indicators for parks or networks should be accomplished during the workshop using the groups' knowledge of the resource and the information in the geologic monitoring parameters. The following is a brief description of the significance of each geoindicator:

*<u>Frozen ground activity</u>: Permafrost influences natural and managed ecosystems, including forests, grasslands and rangelands, mountains and wetlands, and their hydrological systems. It is an agent of environmental change that affects ecosystems and human settlements. Permafrost may enhance further climate change by the release of carbon and other greenhouse gases during thawing. It is estimated that nearly 1/4 of the world's terrestrial carbon is tied up in dead organic mater in the active layer and in permafrost: long-term climate warming would facilitate decomposition and drying, releasing huge quantities of methane and CO2 [see wetlands extent, structure and hydrology]. Permafrost can result in serious and costly disruptions from ground subsidence, slope failure, icings, and other cryogenic processes.

*<u>Glacier fluctuations</u>: Glaciers are highly sensitive, a natural, large-scale, representative indicator of the energy balance at the Earth's surface in polar regions and high-altitudes. Their capacity to store water for extended periods exerts significant control on the surface water cycle. The advance and retreat of mountain glaciers creates hazards to nearby human structures and communities through avalanches, slope failure, catastrophic outburst floods from ice and moraine-dammed lakes. Notwithstanding local glacier advances, the length of mountain glaciers and their ice volume has decreased throughout the world during the past century or two, providing strong evidence for climate warming, though there may also be local correlations with decreasing precipitation. It is estimated that the European Alps have lost more than half their ice in the past century

*<u>Desert biotic crusts and pavements</u>: Desert surface crusts are important because they protect the underlying fine material from wind erosion.

*<u>Dune formation and reactivation</u>: Moving dunes may engulf houses, fields, settlements and transportation corridors. They also provide a good index of changes in aridity. Coastal dunes are important determinants of coastal stability, supplying, storing and receiving sand blown from adjacent beaches. Dunes play an important role in many ecosystems (boreal, semi-arid, desert, coastal) by providing morphological and hydrological controls on biological gradients.

*<u>Wind erosion</u>: Changes in wind-shaped surface morphology and vegetation cover that accompany desertification, drought, and aridification are important gauges of

environmental change in arid lands. Wind erosion also affects arid and semi-arid regions, by removing topsoil, seeds and nutrients.

Dust storm magnitude, duration, and frequency: Local, regional and global weather patterns can be strongly influenced by accumulations of dust in the atmosphere. Dust storms remove large quantities of surface sediments and topsoil with nutrients and seeds. Wind-borne dust, especially where the grain size is less than 10 µm, and salts are known hazards to human health. Dust storms are also an important source of nutrients for soils in desert margin areas.

Coral chemistry and growth patterns: The combination of abundant geochemical tracers, sub-annual time resolution, near-perfect dating capacity, and applicability to both current and past climatic changes establishes corals as one of the richest natural environmental recorders and archives. A 30 cm-diameter coral colony growing at an average rate of 1 cm/yr will provide 20-25 years of baseline data, whereas massive colonies 3-6 m high may provide historical data for extensive tracts of tropical ocean, such as are not otherwise available.

Relative sea level: Changes in RSL may alter the position and morphology of coastlines, causing coastal flooding, waterlogging of soils and a loss or gain of land. They may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce salt-water intrusion into aquifers, leading to salinization of groundwater. Coastal ecosystems are affected, for example, by increased salt stress on plants. A changing RSL may also have profound effects on coastal structures and communities. Low-lying coastal and island parks are particularly susceptible to sea-level rise. It is estimated that 70% of the world's sandy beaches are affected by coastal erosion induced by RSL rise.

*Shoreline position: Changes in the position of the shoreline affect transportation routes, coastal installations, communities, and ecosystems. The effects of shoreline erosion on coastal communities and structures can be drastic and costly. It is of paramount importance for coastal parks to know if local shorelines are advancing, retreating or stable. Rates of recession as high as 5-10 m/yr have been measured in many places around the world, and much higher rates have been recorded locally. Coastal erosion in the USA alone is estimated to cost $700 million annually.

Groundwater chemistry in the unsaturated zone: Changes in recharge rates have a direct relationship to water resource availability. The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality.

Groundwater level: Groundwater is the major source of water in many regions. In the USA, more than half the drinking water comes from the subsurface: in arid regions it is generally the only source of water. The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge: groundwater mining is a terminal condition.

Groundwater quality: Groundwater is important for human consumption, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of baseflow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function. It is important to detect change and early warnings of change both in natural systems and resulting from pollution.

*Karst activity: It is estimated that karst landscapes occupy up to 10% of the Earth's land surface, and that as much as a quarter of the world's population is supplied by karst water. The karst system is sensitive to many environmental factors. The presence and growth of caves may cause short-term problems, including bedrock collapse, disparities in well yields, poor groundwater quality because of lack of filtering action, and instability of overlying soils.

Lake levels and salinity: The history of fluctuations in lake levels provides a detailed record of climate changes on a scale of ten to a million years. Lakes can also be valuable indicators of near-surface groundwater conditions.

Surface water quality: Clean water is essential to human survival as well as to aquatic life. Pathogens such as bacteria, viruses and parasites can make polluted waters among the world's most dangerous environmental problems. Water quality data are essential for the implementation of responsible water quality management, for characterizing and remediating contamination, and for the protection of the health of humans and aquatic organisms.

*Stream channel morphology: Channel dimensions reflect magnitude of water and sediment discharges. An understanding of stream morphology can help delineate environmental changes of many kinds. Changes in stream pattern, which can be very rapid in arid and semi-arid areas, can limit land use and alter habitat, such as on islands in braided streams and meander plains, or along banks undergoing erosion.

Streamflow: Streamflow directly reflects climatic variation. Changes in streams and streamflow are indicators of changes in basin dynamics and land use.

*Stream sediment storage and load: Sediment load determines channel shape and pattern [see stream channel morphology]. Changes in sediment yield reflect changes in basin condition, including climate, soils, erosion rates, vegetation, topography and land use. Fluctuations in sediment discharge affect many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with the sediment load. Stream deposits also represent huge potential sinks for, and sources of, contaminants.

Wetlands extent, structure and hydrology: Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands mediate large and small-scale environmental processes by altering downstream catchments. Wetlands can affect local hydrology by acting as a filter, sequestering and storing heavy metals and other pollutants, such as Hg, and serving as flood buffers and, in coastal zones, as storm defenses and erosion controls.

*Volcanic unrest: Natural hazards associated with eruptions of the world's 550 or so historically active volcanoes pose a significant threat to about 10% of the world's population, especially in densely-populated circum-Pacific regions. By the year 2000, more than half a billion people will be at risk.

*Seismicity: Earthquakes constitute one of the greatest natural hazards to human society. Between 1960 and 1990 earthquakes killed about 439,000 people worldwide and caused an overall economic loss of some $ 65 billion. Surface effects include uplift or subsidence, surface faulting, landslides and debris flows, liquefaction, ground shaking, and tsunamis ('tidal' waves caused by undersea tremors). Damage to buildings, roads, sewers, gas and water lines, power and telephone systems, and other built structures commonly occurs.

*Slope failure (landslides): Annual property damage from landslides worldwide is estimated in the tens of billions of dollars, with more than $1.5 billion in annual losses in the USA alone. There are innumerable small to medium-size slope failures that cumulatively impose costs to society as great or greater than the large infrequent catastrophic landslides that draw so much attention. Landslides can alter habitat and impact resources down slope and add sediment to waterways.

*Soil and sediment erosion: Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. In the USA, soil has recently been eroded at about 17 times the rate at which it forms.

*Soil quality: As one of Earth's most vital ecosystems, soil is essential for the continued existence of life on the planet. As sources, stores, and transformers of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, determining the agricultural production capacity of the land. Soils buffer and filter pollutants, they store moisture and nutrients, and they are important sources and sinks for CO_2, methane and nitrous oxides. Soils are a key system for the hydrological cycle [see groundwater chemistry in the unsaturated zone]. Soils also provide an archive of past climatic conditions and human influences.

*Subsurface temperature regime: The thermal regime of soils and bedrocks exercises an important control on the soil ecosystem, on near-surface chemical reactions (e.g. involving groundwater), and on the ability of these materials to sequester or release greenhouse gases. It may affect the type, productivity and decay of plants, the availability and retention of water, the rate of nutrient cycling, and the activities of soil microfauna. It is also of major importance as an archive of climate change, indicating changes in surface temperature over periods of up to 2-3 centuries, for example in regions without a record of past surface temperatures. In permafrost, the ground temperature controls the mechanical properties of the soils, especially during the freeze-thaw transition in the active layer.

*<u>Sediment sequence and composition</u>: The chemical, physical and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs.

*<u>Surface displacement</u>: Most surface displacements have but minor effects on landscapes and ecosystems. However, there are exceptions, such as where drainage channels are suddenly displaced by faults, or where seismically-induced uplift raises intertidal ecosystems above sea-level. Moreover, extraction of fluids can induce land subsidence and cause flooding, especially of coastal parklands near sea-level. Subsidence damages buildings, foundations and other built structures.

What does geologic monitoring look like and who does it?

Geologic monitoring involves collecting information through observing, measuring and sampling elements of geologic processes at work and their resulting geologic features. This can be done on the ground or remotely and by an individual or a team. Some monitoring is very complex requiring sophisticated instruments employed by scientists and trained technicians; while other types of geologic monitoring utilizes standard measuring and recording devices that others can operate with little training required.

When parks consider vital indicators, it is important to be familiar with the monitoring activities they can expect and any potential for damage to park resources. No one wants to have a swarm of rock hammer-wielding geologists show up in their park - And, that is not what it takes to measure geoindicators. Since geoindicators are measures of processes at or near the surface that change rapidly, they focus less on the hard rock and more on rates of moving material, and physical and topographic change. Activities associated with monitoring of geoindicators include using GPS, aerial photography, seismography, temperature readings, remote sensing, surveying, measuring flow rates, gathering meteorology data, and others. Monitoring of geoindicators can easily be conducted in a resource-sensitive and park friendly manner.

Who should do the geologic monitoring? In many instances a team will do monitoring. In some cases scientists and highly trained technicians will be needed to do the geologic monitoring but often other park staff or non-park personnel such as students, retirees, or volunteer participants can carry out routine measurements or observations. However, in all instances park personnel should be “active” members of the monitoring team. Park involvement will insure that the NPS stays connected to the monitoring project, park needs continue to be addressed, management is kept informed, and information transfer extends throughout the NPS network. Because park staff are located on-site they will probably be most effective in implementing field activities and recording the data in park databases, such as, GIS and Synthesis.

Guidance for the design of monitoring programs for geologic resources in the 32 monitoring networks

This section outlines the recommend steps each monitoring network should follow to ensure adequate planning for the monitoring of geologic indicators. Although a few monitoring networks may have already addressed some of these steps, the guidance outline should help all networks to ensure a comprehensive review of their geologic monitoring needs.

A. Identify geologic expertise:

1. Most networks do not have geologic expertise and will need to develop a team of specialists to consult with them for evaluation and design of geologic monitoring. The Geologic Resources Division is available to all networks to help locate geoscientists for this purpose - Contact Bob Higgins, Supervisory Geologist, GRD for assistance, bob_higgins@nps.gov, or call (303) 969-2018.

2. Geologic expertise will be identified from the geologic community

a) GRD geology staff and other NPS geologists
b) U.S. Geological Survey
c) American Association of State Geologists
d) Geological Society of America
e) University partners
f) Museum geologists

3. Networks should recruit geoscientists to participate in workshops, review proposed monitoring strategies and design monitoring protocols.

B. Have geoscience contact(s) compile a summary of existing geologic monitoring and information sources for the network.

C. Have geoscientists participate in network workshops to:

1. Rate importance of 27 geoindicators and determine which ones are significant for monitoring in parks within the network;

2. Compile a description of alternatives (methods) for comprehensive monitoring of all priority geoindicators of environmental change, including any potential for using existing monitoring done by other organizations;

3. Work with network resource specialists to identify preferred options for implementing geologic monitoring in parks (cost effective, resource friendly, easy to measure and replicative for time series analysis with adequate accuracy and precision);

4. Write a geology panel report for the network (based on network format or outline below);

Introduction
Summary of group discussion
Results - for each vital sign chosen, report the following:

- Management Issue:
- Monitoring Question Addressed:
- Vital Sign:
- What ecosystems does this Vital Sign apply to?
- Why was this vital sign chosen?
- Other information (monitoring information, protocols, costs, potential partners, related on-going research, suggested inventory needs, reviewers, etc.):
- Contact person:

Methods
Design and Implementation

5. Recommend specialists to design specific monitoring protocols (in some instances, panel members can do this at the workshop).

D. Continuing Geologic Monitoring Process

1. Networks will need to incorporate geologic resource monitoring into their ecosystem monitoring program under GPRA goal Ib3 and their long-term monitoring programs.

2. The NPS Geologic Resource Division will continue to be available to parks and networks to implement monitoring strategies, facilitate partnerships and reevaluate monitoring protocols as the program evolves.

3. In many cases, the geoscientists that participate in network workshops will be willing to assist with developing partnership agreements to collect, process and analyze data.

Appendices

A. Desert Biotic Crusts and Pavements
B. Dune Formation and Reactivation
C. Frozen Ground Activity
D. Glacier Fluctuations
E. Karst Processes
F. Relative Sea Level
G. Sediment Sequence and Composition
I. Seismicity
J. Shoreline Position
K. Slope Failure (landslides)
L. Soil and Sediment Erosion
M. Soil Quality
N. Stream Channel Morphology
O. Stream Sediment Storage and Load
P. Subsurface Temperature Regime
Q. Surface Displacement
R. Volcanic Unrest
S. Wind Erosion